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Exploration System of Systems Programmatic Requirements and Guidelines Document

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1 Scope

1.1 Identification

This document is a summary of the NASA Exploration System of Systems (ESS) Programmatic Requirements and Guidelines. When combined with the Exploration System of Systems Technical Requirements (ESMD-RQ-0010), they represent a first-level functional decomposition of the requirements expressed in *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration, January, 2004*. The Vision is expressed in requirements form in the *Level 0 Exploration Requirements for the National Aeronautics and Space Administration*, SA-0001, May 4, 2004. The phrase "responsible program" is used extensively in this document. It is intended to identify the responsible NASA organization during a given phase of a mission, or project lifecycle (e.g, flight operations).

The capabilities expressed in this document will evolve and expand over time, employing the Spiral Development Process to develop human-crewed, cargo, and robotic flight and ground systems to accomplish The Vision. Emphasis has been on the Crew Exploration Development and Test requirements (Exploration Spiral 1) and the Lunar Exploration requirements (Exploration Spirals 2&3), that provide long-duration human lunar exploration capability. Requirements development for Exploration Spiral 4 and beyond (human-Mars exploration) will be undertaken in the future. The controlling authority for this document is the Exploration Systems Mission Directorate (ESMD), Requirements Formulation Division, NASA Headquarters.

1.2 Document Overview

This document provides the Exploration System of Systems Programmatic Requirements and Guidelines. The contents of this document do not flow-down into individual exploration systems technical requirements. Rather, they provide direction and best practices which are expressed in system development contracts, as part of the Exploration System acquisition process. The Exploration Systems hierarchy shown in Figure 1 explains the hierarchy of requirements documents that flow down from The Vision. The relationship of this document to other Exploration Systems requirements documents is shown in Figure 2.

Section 1 of this document contains background information with no direct requirements. Section 2 contains the applicable documents that Explorations Systems must comply with, as specified; Section 2 also contains reference documents that are for information only, that do not contain compliance requirements. Section 3 contains Exploration System of Systems Programmatic Requirements and Guidelines, beginning in Section 3.1. Section 4 contains a glossary of exploration terms, an acronym list and a requirements taxonomy table.

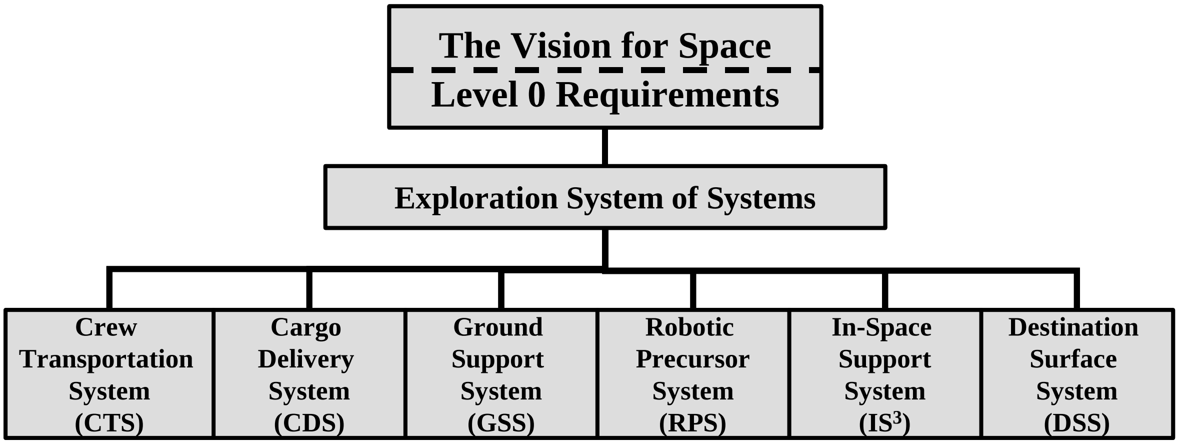

Figure 1: Exploration System of Systems Hierarchy

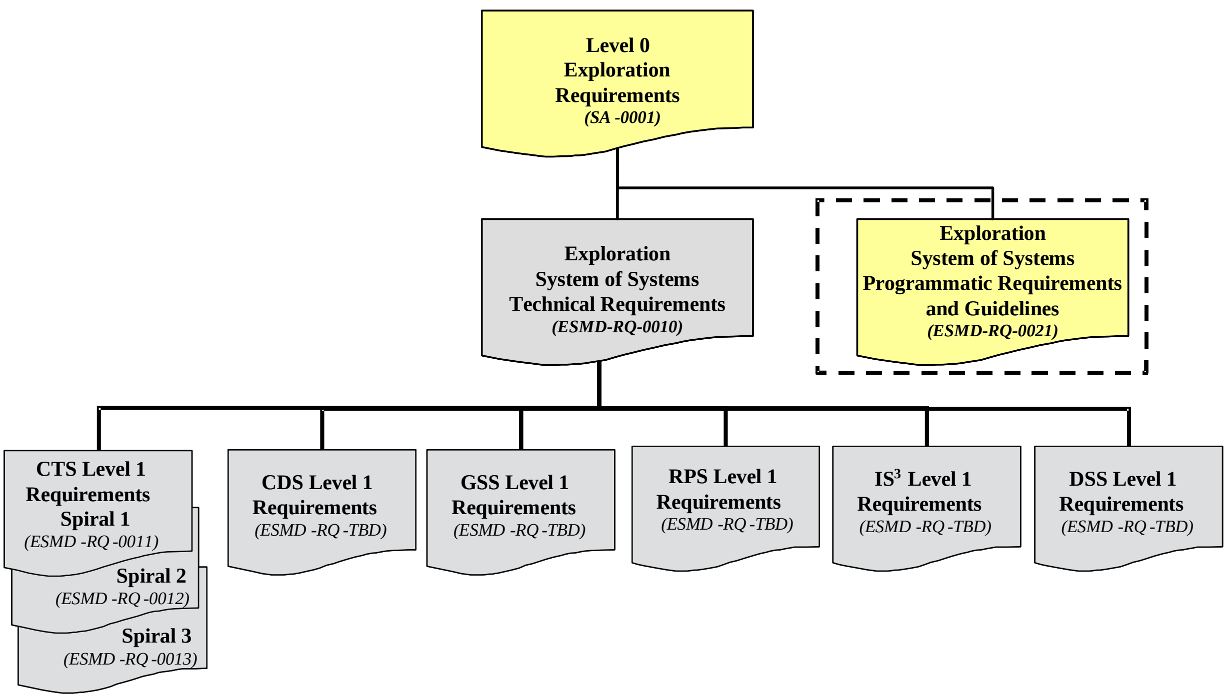

Figure 2: Exploration System Requirements Document Tree

2 Documents

2.1 Applicable Documents

The following documents form a part of this requirements document to the extent specified herein. The version of the document applicable will be the latest revision at the time of contract award unless otherwise specified.

2.1.1 Government Documents

The Vision for Space Exploration (NP-2004-01-334-HQ)

Level 0 Exploration Requirements for the National Aeronautics and Space Administration (SA-0001)

2.1.2 Non-Government Documents

Reserved.

2.2 Reference Documents

The following documents specified herein are for reference only. Current document versions are referenced.

2.2.1 Government Documents

ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Report
ESMD-RQ-0006, Lunar Architecture Broad Trade Study Final Report
ESMD-RQ-0016, STTP-2 Meeting Minutes
ESMD-RQ-0018, Draft Polar Lunar Landing Site Rationale
ISBN 0-309-07031, Astronomy and Astrophysics in the New Millenium, National Academies of Science
NASA-STD-3000, Vol. I-IV, Man-Systems Integration Standards
NPR 1000.2, NASA Strategic Management Handbook
NPD 1050.1G, Authority to Enter into Space Act Agreements
NPD 1080.1A, NASA Science Policy
NPD 1200.1B, Internal Management Controls and Audit Liaison
NPD 1280.1, NASA Management System Policy
NPD 1360.2A, Initiation and Development of International Cooperation in Space and Aeronautics Programs, NPD 1360.2A
NPR 1385.1, Public Appearances of NASA Astronauts and Other Personnel
NPD 1387.1E, NASA Exhibits Program
NPR 1387.1, NASA Exhibits Program
NPD 1387.2F, Use, Control, and Loan of Lunar Samples for Public and Educational Purposes
NPD 1600.2C, NASA Security Policy
NPR 1620.1A, Security Procedural Requirements
NPR 1800.1, NASA Occupational Health Program Procedures
NPR 1800.2B, NASA Occupational Health Program

NPD 1810.2, NASA Occupational Medicine Program
NPD 1820.1B, NASA Environmental Health Program
NPD 2200.1, Management of NASA Scientific and Technical Information (STI)
NPR 2200.2A, Requirements for Documentation, Approval, and Distribution of NASA Scientific and Technical Information (STI)
NPD 2800.1, Managing Information Technology
NPR 2800.1, Managing Information Technology
NPD 2810.1C, NASA Information Security Policy
NPR 2810.1, Security of Information Technology
NPD 2820.1A, NASA Software Policies
NPD 3310.1A, Distinguishing between Contractor and Civil Service Functions
NPD 5101.32B, Procurement
NPR 5600.2B, Statement of Work (SOW); Guidance for Writing Work Statements
NPR 6000.1F, Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components
NPD 7100.10D, Curation of Extraterrestrial Materials
NPD 7120.4B, Program/Project Management
NPR 7120.5B, NASA Program and Project Management Processes and Requirements Approval Authorities for Facility Projects. NPD 7330.1F, Approval Authority for Facility Projects
NPD 7500.1A, Program and Project Logistics Policy
NPR 7500.1, NASA Technology Commercialization Process
NPR 8000.4, Risk Management Procedural Requirements
NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft NPD 8020.7F
NPR 3020.12B, Planetary Protection Provisions for Robotic Extraterrestrial Missions
NPD 8610.7A, Launch Services Risk Mitigation Policy for NASA-Owned Or NASA-Sponsored Payloads
NPD 8610.23A, Technical Oversight of Expendable Launch Vehicle (ELV) Launch Services
NPD 8610.24A, Expendable Launch Vehicle (ELV) Launch Services Pre-launch Readiness Reviews
NPD 8700.1B, NASA Policy for Safety and Mission Success
NPD 8700.2A, NASA Policy for Safety and Mission Assurance (SMA) for Experimental Aerospace Vehicles (EAV)
NPD 8700.3A, Safety and Mission Assurance (SMA) Policy for NASA Spacecraft, Instruments, and Launch Services
NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems
NPR 8705.3, Safety and Mission Assurance (SMA) Requirements for Experimental Aerospace Vehicles (EAV)
NPR 8705.4, Risk Classification for NASA Payloads
NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects
NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation
NPR 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs
NPR 8715.x, NASA Range Safety Program (in draft)
NPR 8715.3, NASA Safety Manual
NPD 8720.1B, NASA Reliability and Maintainability (R&M) Program Policy
NPD 8730.2B, NASA Parts Policy
NPD 8730.4A, Software Independent Verification and Validation (IV&V) Policy
NPR 8735.2, Management of Government Safety and Mission Assurance Surveillance Functions for

NASA Contracts
NPD 8820.2A, Design and Construction of Facilities
NPR 8820.2E, Facility Project Implementation Guide
NPD 8820.3, Facility Sustainable Design
NPD 8900.1F, Medical Operations Responsibilities in Support of Human Space Flight Programs
NPD 9501.1G, NASA Contractor Financial Management Reporting System
NPR 9501.2D, NASA Contractor Financial Management Reporting
NPD 9501.3A, Earned Value Management
NPR 9501.3, Earned Value Management Implementation on NASA Contracts

2.2.2 Non-Government Documents

Reserved.

3 System Requirements

The following text does provide, nor represent specific requirements, but is provided as context for the requirements that follow, beginning in section 3.1.

System Description
The Vision for Space Exploration requires NASA to implement an effective and exciting program of exploration and discovery. Sustained and affordable human and robotic missions will extend the human presence across the solar system. Innovative technologies, knowledge, and infrastructures will need to be developed. Over the next two decades, NASA plans to develop a number of new capabilities and systems that are critical to enabling safe and successful human and robotic missions. Vehicle elements to be fielded within this System of Systems will use a "spiral development" approach. In spiral development, the detailed end-state requirements are not known at program initiation. Requirements are refined through system development and demonstration, risk management and continuous user feedback. This approach will build on the experience gained in early Exploration Spirals, to provide flexibility in responding to scientific discoveries and to incorporate new technologies. Robotic Precursor Missions to the Moon and Mars will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, resource identification). In addition, Robotic Precursor Missions will serve as opportunities for advanced technology demonstrations.

Exploration Spiral 1/Crew Exploration Development and Test
Exploration Spiral 1 will establish the capability to test and checkout Crew Transportation System (CTS) elements in Low Earth Orbit (LEO) in preparation for future human exploration missions to the Moon. The capabilities necessary to satisfy the Spiral 1 objectives consist of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and ground support infrastructure. The CEV and CLV will safely transport the crew from the surface of the Earth to LEO, and return them to the Earth's surface at the completion of the mission. Demonstration of CEV and launch system performance are critical to enabling Spiral 1 objectives of safe transportation of the crew. Successive demonstrations of the CEV and launch system (including the ability to perform ascent and entry aborts) will begin with a series of risk reduction flight tests, and lead up to crewed CEV operational capability to support human exploration

missions beyond LEO. The CEV must have a high degree of automated control to accomplish the early un-crewed test flights. Other CEV flights will test the automated rendezvous and docking systems, to develop the skills and techniques that will be needed for follow-on exploration missions. As exploration capabilities necessary for future spirals are developed, they will be tested with the CEV in the space environment to prepare for future exploration missions. Robotic exploration missions during Spiral 1 will investigate the lunar environment and provide the needed information to prepare for safe landings and human exploration of the lunar surface.

Spiral 1 Flight Hardware Functional Descriptions:
Crew Launch Vehicle:

Will provide the propulsive force necessary to launch the CEV into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation functions during ascent and entry, including mission aborts. Will also provide all maneuvering capability during orbit operations and entry (including aborts).

Robotic Precursor System:
Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 2/Global Lunar Access for Human Exploration
Exploration Spiral 2 will establish the capability to conduct human exploration missions to any location on the surface of the Moon without pre-positioned surface infrastructure. This Spiral 2 capability will likely be utilized to conduct human exploration of potential lunar base sites prior to the delivery of habitats and surface power systems (Destination Surface Systems). This capability could also be utilized to place humans at the lunar base camp location for habitat and surface power systems final assembly tasks. Once the lunar base is established, this Spiral 2 capability could be utilized to explore locations which are not accessible via surface mobility assets. The systems necessary to satisfy Spiral 2 objectives consist of those developed in Exploration Spiral 1, or derivatives of those capabilities, plus Earth Departure Stage(s) (EDS) necessary to transport elements to the lunar vicinity as well as the Lunar Surface Access Module (LSAM) that will provide the capability for the crew to access the lunar surface. The Cargo Delivery System will deliver un-crewed elements of the Crew Transportation System into LEO and/or lunar orbit (e.g., EDS). Spiral 2 will include successive flight tests to demonstrate the flight characteristics of the CEV, EDS, and LSAM to gain knowledge of how the systems perform at greater distances from Earth and increasing levels of autonomy. Focused robotic precursor technology demonstration missions to Mars are also anticipated within this Spiral.

Spiral 2 Flight Hardware Functional Descriptions:
Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV will also provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV and LSAM) from LEO to lunar orbit, and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface and during return to lunar orbit; will provide crew habitation during lunar surface operations. In addition, the LSAM will provide the capability for the crew to conduct science and perform routine Extra-Vehicular Activity (EVA) on the surface of the Moon.

Cargo Delivery System:

Will deliver un-crewed elements of the CTS into LEO and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS.

Robotic Precursor System:
Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

Exploration Spiral 3/Lunar Base and Mars Testbed
Exploration Spiral 3 will establish the capability to conduct routine human long-duration missions at a lunar base to test out technologies and operational techniques for expanding the human presence to Mars and beyond. Missions in Spiral 3 will extend up to several months in duration at the lunar poles or equatorial region in order to serve as an operational analog of future Mars missions. Spiral 3 will require the development and deployment of habitats and surface power systems. These Destination Surface Systems (DSS) will be delivered to a selected location in the polar or equatorial region by the Cargo Delivery System (CDS). The number, type, and sequencing of these CDS missions have not yet been specifically defined. Once the surface systems are in place, successively longer missions will be conducted to increase the understanding of system technical performance (including health and human systems), and to provide increasing levels of operational autonomy capabilities that will be necessary for future human Mars exploration missions. The Spiral 2 capability for global access is retained in Spiral 3, and will allow exploration missions to locations not accessible from the base camp via surface mobility

assets.

Spiral 3 Flight Hardware Functional Descriptions:

Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation and health maintenance functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV also will provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV, LSAM, and cargo vehicles) from LEO to lunar orbit and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface, and return to lunar orbit. In addition, the LSAM will provide the capability for the crew to perform EVA on the surface of the Moon in order to transition to the surface elements for the long duration missions. The LSAM will remain on the surface of the Moon during the long-duration surface missions.

Cargo Delivery System:

Will deliver un-crewed elements of the Crew Transportation System into Low Earth Orbit and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS. The CDS will also deliver elements of the DSS from a low lunar orbit to the desired location on the surface of the Moon. The CDS elements have not been completely identified at this time, but should include a Cargo Launch Vehicle, Cargo Destination Landing System, and the EDS.

Destination Surface System:

Will provide crew support capabilities to enable long-duration surface missions. The elements that comprise this system have not been completely defined at this point, but will provide functionality including habitation, communication, power, extended range mobility, enhanced science capabilities, etc. DSS will provide the capability for the crew to conduct long-duration surface science, and perform EVA on the surface of the Moon.

Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

Ground Support System:
Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

3.1 Constellation Programmatic Requirements

EPR0580 The responsible program will plan and execute Exploration missions as part of a spiral development strategy.

Rationale : The necessary tools must be provided to perform mission planning. Exploration missions must be planned and executed within the context of a given spiral campaign or strategy. This campaign or strategy should include a "build up" approach to demonstrate capabilities and technologies needed for future missions/campaigns. Training for flight and ground crews must be accomplished in order to successfully execute Exploration missions.

EPR0550 The responsible program will initiate a series of robotic missions to the Moon launching no later than 2008 to prepare for and support future human exploration activities.

Rationale : This requirement was derived from the Exploration Level 1 Objective (1.1): "Starting no later than 2008, NASA shall initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities." This requirement is a programmatic schedule constraint. The Robotic Lunar Exploration Program is scheduled to launch its first mission by 2008.

EPR0520 The responsible program will acquire a Crew Exploration Vehicle (CEV) and the necessary launch capability to provide an initial operational capability no later than 2014.

Rationale : This requirement is flowed down from Level 1 Exploration Objective (3): "NASA shall conduct the initial test flight for the crew exploration vehicle before the end of the decade in order to provide an operational capability to support human exploration missions no later than 2014." This requirement is a programmatic schedule constraint.

EPR0540 The responsible program will perform an initial flight test of a Crew Exploration Vehicle by the end of 2010.

Rationale : This requirement is flowed down from Level 1 Exploration Objective (3): "NASA shall conduct an initial test flight for the Crew Exploration Vehicle before the end of the decade in order to provide an operation capability to support human exploration missions no later than 2014." This requirement is a programmatic schedule constraint.

EPR0510 The responsible program will conduct an extended duration human exploration mission to the lunar surface as early as 2015, but no later than the year 2020.

Rationale : This requirement is flowed down from Level 1 Exploration Objective (1.2): "NASA shall conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020, in preparation for human exploration of Mars and other destinations." This requirement is a programmatic schedule constraint.

EPR0560 The responsible program will develop standard Interface Requirements Documents (IRD) at the Exploration System of Systems level including the following:
a) Communications requirements (including Command and Control)
b) Docking interface requirements to include utilities and consumables transfer
c) Rendezvous and proximity operations sensor and target requirements
d) Human Systems requirements (e.g., habitation, consumables, etc.)
e) TBD

Rationale : IRD(s) are needed to define interface requirements across the System of Systems, to insure interoperability and sustainability. The interfaces specified in this requirement must be defined to insure the level of interoperability required to accomplish Exploration missions. These interfaces must be determined early, since exploratino systems acquisition is staggered over considerable time.

EPR0630 The responsible program will define the natural environments for the Exploration System of Systems and document them in an ESS Natural Environments Definition for Design (NEDD) document.

Rationale : There are three environments that must be addressed during system design and development. Induced environments should be handled at lower levels through technical requirements. Environmental impact of Exploration missions on the Solar System's environment should be dealt with through applicable NASA Policy Documents (NPD). The NEDD deals with the natural environments throughout the solar system which any mission of the Exploration System of Systems (ESS) would encounter (in-space, and destination specific). An ESS-level NEDD will ensure that elements of the ESS are designed to operate in the appropriate natural environments.

EPR0640 The responsible program will design the Exploration System of Systems to be operated in and after exposure to the natural environments as defined in the ESS NEDD document.

Rationale : The ESS-level NEDD must be used when making decisions with regard to mission architectures. This requirement also serves as a parent to require use of this NEDD by system developers.

EPR0660 The responsible program will develop and execute an Integrated Logistics Support plan.

Rationale : By approaching logistics in an integrated fashion, Constellation Systems can assess opportunities for standardization and commonality for technical and programmatic benefits. The strategy for developing and executing this System of Systems capability should be captured in an integrated logistics support plan.

EPR0620 The responsible program will develop Educational Public Outreach (EPO) and Public Awareness campaigns.

Rationale : This requirement is flowed down from Level 0 Exploration Requirement (6): "NASA shall identify and implement opportunities within mission for the specific purposes of inspiring the Nation." EPO and Public Awareness campaigns are a tool for NASA to communicate knowledge, and well as inspiring the next generation of scientists, mathematicians, and engineers. Maintaining public awareness is also a means of providing a sustainable implementation of The Vision for Space.

3.2 Constellation Programmatic Guidelines

EPG0850 The responsible program should design, build, test, certify, and operate the Exploration System of Systems to minimize the potential for loss of life, and major illness (e.g., lifetime risk of fatal cancer) or trauma.

Rationale : NASA's Safety Policy is to protect the Public, NASA Workforce and Flight Crews. Although space flight involves operations in a hazardous / unforgiving environment and the risk to personnel cannot be eliminated, the risk can be minimized. The Program must weigh any design or operational decisions against how it would affect risk to personnel and ensure that risk is minimized to the maximum extent allowable within the constraints of schedule, cost and mission execution. This process must continue throughout all phases of the program from design through mission completion and final disposal of the hardware.

EPG0860 The responsible program should, to the maximum extent practical, design the Exploration System of Systems to provide for crew survival in the event of catastrophic events.

Rationale : The Columbia Accident Investigation Board (CAIB) report states, "Future crewed-vehicle requirements should incorporate the knowledge gained from the Challenger and Columbia accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed." The Apollo 13 mission is an example of the crew surviving a catastrophic event. Human spaceflight systems should provide for crew survival even when catastrophic events occur. This Guideline reinforces the requirements levied by NPR 8705.2, Human Rating Requirements for Space Systems and ensures crew survival is always considered when making Programmatic or design decisions.

EPG0830 The responsible program should separate crew from cargo for launches of exploration missions to the maximum extent practical.

Rationale : This guideline is flowed down from Level 1 Exploration Objective (2): "NASA shall separate crew from cargo for launches of exploration missions to the maximum extent practical." Launch of the crew element separate from cargo may facilitate design of a human rated launch system with more robust abort options and improved crew survival margins than offered by the current Shuttle system. However, requiring multiple launches to accomplish a single crewed mission could compromise mission success.

EPG0810 The responsible program should simplify interfaces between systems, segments, and elements, and between organizations where such simplification will increase reliability, reduce risk, and minimize cost.

Rationale : Opportunities to improve system reliability and affordability of the Exploration System of Systems must be actively sought out. Simplified interfaces should be used, unless there is an appreciable loss of system performance as a result.

EPG0820 The responsible program should utilize common subsystems, interfaces, and software across the Exploration System of Systems where such commonality will reduce risk and minimize cost.

Rationale : Commonality is an accepted practice for improving system reliability, and can also generate cost savings. Commonality can also simplify the support and logistics components.

EPG0840 The responsible program should, to the maximum extent practical, design the Exploration System of Systems to allow for the use of commercially provided items and services.

Rationale : This guideline is flowed down from the Level 0 Exploration Requirement (5): "NASA shall pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration mission beyond low Earth orbit." Private industry may provide innovations that lead to lower cost spaceflight, and provide for a greater range of mission options.

4 Glossary and Acronyms

4.1 Glossary

Abort Early mission termination due to failure(s) that preclude mission continuation. Return to Earth of the crew is accomplished inside the spacecraft designed for Earth return and landing (see Abort to Earth, Abort to Orbit).

Abort to Earth Early mission termination, with direct return to the Earth's surface as the immediate objective.

Abort to Orbit An early mission termination that has an immediate objective of placing a crewed flight system in Earth (or destination vicinity) orbit, prior to return to the Earth's surface.

Annunciate To provide a visual, tactile or audible indication.

Ascent The function of liftoff from the Earth (or mission destination) surface, to spacecraft insertion into Earth/destination orbit.

Automated control Automatic, as opposed to human operation or control of a process, equipment or a system; or the techniques and equipment used to achieve this. Automation is the control or execution of actions with no human interaction. Automated control does not exclude the capability for manual intervention / commanding, but manual intervention / commanding is explicitly not required to accomplish the function.

Autonomous operations Defined as a flight vehicle operating independent of external commands or control (i.e., commands from mission control on Earth). Autonomous operations can be fully automated or require some degree of manual commanding/intervention by the onboard crew. Autonomous operations that do not require onboard crew involvement are, by definition, automated; therefore, the term "autonomous operations" used in the requirements assumes onboard crew involvement in the operations.

Berthing A method of mating two or more Exploration elements in space. During a berthing operation, the two elements are mechanically connected prior to the structural capture and final mating (i.e., one element grapples the other with a robotic arm). One element controls the trajectory and attitude of the other element for the contact and capture. Final mating is generally performed by the berthing mechanism (also see docking).

Cargo Delivery System (CDS) The CDS encompasses the capability to deliver all non-CEV flight elements needed to accomplish human exploration objectives. At such time as CDS elements dock with the CEV, they are part of a human crew occupied system, and are considered part of the CTS.

Cargo Launch Vehicle The Cargo Launch Vehicle is an element of the Cargo Delivery System. The Cargo Launch Vehicle will perform the ascent function for non-crewed elements of the CTS (EDS, LSAM), into an Earth Orbit. Since the Cargo Launch Vehicle will not carry human crew, it will not require Human-Rating.

Catastrophic Hazard A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or major systems or vehicle destruction during the mission. (From NPR 8715.3 Safety Manual)

Consumables Resources that are consumed in the course of conducting a given mission. Includes propellant, power, habitability items (e.g., gaseous oxygen), and crew supplies.

Contingency EVA Capability An EVA capability provided to deal with critical failures or circumstances, which are not adequately protected by redundancy or other means.

Crew Exploration Vehicle (CEV) The CEV provides crew habitation and Earth reentry capability for all Exploration Spirals.

Crew Exploration Vehicle Launch Segment (CEVLS) The CEVLS consists of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and all the dedicated ground support infrastructure necessary to launch the CEV to Earth orbit.

Crew Launch Vehicle (CLV) The CLV is an element of the CTS. The CLV will be human-rated, and will deliver the CEV into a mission-specific Earth Ascent Target Orbit.

Crew Member Human onboard the spacecraft or space system during a mission.

Crew Transportation System (CTS) The CTS encompasses the flight elements needed to deliver a human crew from Earth to a mission destination, and return the crew safely to Earth. The CTS must interact with the Ground Support System (GSS) during all Spirals; current architectures require delivery of the EDS and LSAM to Earth orbit through use of the CDS.

Critical Hazard A condition that may cause a severe injury or occupational illness, loss of mission, or major property damage to facilities, systems, or flight hardware.

Day Defined as an Earth day of 24 hours.

Destination Surface System (DSS) The DSS encompasses all elements (exclusive of the surface lander that transports the crew to the destination surface) necessary to enable a long-duration human exploration mission. Examples of DSS elements include a long-duration habitation module, surface power capability, and surface transportation systems. DSS elements will be delivered to the destination surface via the CDS. It is likely that these assets will be pre-deployed in advance of the crew that will utilize them to execute a given Exploration mission.

Destination Surface to Destination Vicinity Phase Starts with the initiation of the ascent (T0) from the destination surface. Representative mission activities include: ascent, abort, and orbit insertion or libration capture. Phase ends after successful destination vicinity insertion/capture.

Destination Vicinity Operations Phase (A) Starts at the successful insertion/capture at the destination vicinity. Representative mission activities include: loiter and phasing, vehicle and system checkout, crew-cargo transfers, undocking and separation. Phase ends at the successful separation of surface lander system for descent burn.

Destination Vicinity Operations Phase (B) Starts after the successful destination orbit insertion or libration point capture, following ascent from destination surface. Representative mission activities include: phasing, vehicle-system checkout, crew-cargo transfer, undocking and separation maneuver, element disposal and/or safing. Phase ends at the completion of the Trans-Earth Injection burn.

Destination Vicinity to Earth Phase Begins with completion of Trans-Earth Injection burn and includes mid-course corrections, cruise to Earth vicinity, element separation and element disposal. Ends with arrival at Earth entry interface or insertion to Earth orbit.

Destination Vicinity to Destination Surface Phase Starts at the initiation of the descent burn from destination vicinity (destination deorbit burn or libration departure burn to destination). Representative mission activities include: descent to destination surface, descent aborts, landing, propulsion system shutdown and safing. For libration architectures, additional activities include orbit capture, phasing, and de-orbit maneuvers. Phase ends when the vehicle has completed all landing activities on the destination surface, including propulsion system shutdown and safing.

Docking A method of mating two or more Exploration elements in space. In a docking operation, the structural mechanisms are brought into contact and captured through independent control of the two vehicles' flight path and attitude. Final mating is generally accomplished by the docking mechanism (also see Berthing).

Earth Ascent Target Orbit The planned orbit, at conclusion of the ascent function.

Earth Departure Stage (EDS) EDS will be used to provide the propulsive force needed to transfer the various flight elements to destination phasing orbits (including the CEV and LSAM).

Earth-Moon Transit Transit of a spacecraft between Earth vicinity and Lunar vicinity in either direction.

Earth Orbit Operations Phase (A) Starts with completion of Earth orbit insertion. Representative activities include: phasing, rendezvous, docking and loiter. Ends with completion of a burn to leave Earth orbit (i.e., Trans-Lunar Injection burn or de-orbit burn).

Earth Orbit to Destination Vicinity Phase Starts after completion of vehicle injection burn (i.e., Trans-Lunar Injection) and includes mid-course corrections, element separation/disposal, and cruise to destination vicinity. Ends with successful insertion/capture at destination vicinity.

Earth to Orbit Phase Starts with liftoff. Representative activities include liftoff through ascent to orbit, ascent crew escape/abort and re-entry/descent during aborts, disposal of elements. Ends with insertion to a stable, 24 hour Earth orbit or return to Earth (in the event of an abort).

Earth Re-entry Phase Begins with arrival at Earth entry interface (for direct re-entry) or completion of Earth orbit injection (for aerocapture), continues through the de-orbit burn and ends with landing on the Earth's surface. Encompasses activities necessary to successfully execute direct-to-Earth aborts during ascent and direct entry return from beyond Earth orbit.

Earth Reference Orbit The orbit designated for assembly of Exploration System elements prior to departure for exploration destinations, defined by the following parameters: Inclination: 28.5-29.0 degrees; Launch Azimuth: 90+/- 5 degrees; Altitude: 307 km - 407 km.

Entry footprint Region on Earth's surface defined by the boundaries of the Earth entry corridor for a given vehicle.

Equatorial Region of the Moon Defined as the area between 0-20 degrees lunar latitude (threshold), with an objective of 0-30 degrees **(TBR)**.

Escape Early mission termination that requires emergency egress of the Crew from the failing spacecraft, possibly using an escape system (e.g., extraction, ejection, escape pod).

Exploration Spiral 1 (Crew Exploration Development and Test) Encompasses the capabilities necessary to insert humans into Earth orbit and return them safely to Earth, employing a post-Space Shuttle flight system. The flight elements of the Exploration Spiral 1 Crew Transportation System are the Crew Exploration Vehicle and CEV Launch Vehicle. Robotic Precursor Missions that are scheduled to launch prior to the Earth orbit demonstration of the Spiral 1 CTS are considered Exploration Spiral 1 missions.

Exploration Spiral 2 (Lunar Global Access for Human Exploration) Encompasses the capabilities necessary to execute human lunar exploration anywhere on the surface of the moon. Lunar global access exploration missions will be 4-7 days in duration on the lunar surface, and do not require pre-deployed surface systems (e.g., Habitation Module or Surface Power). Robotic Precursor Missions scheduled to launch after the Spiral 1 CTS flight demonstration, and prior to the first Spiral 3 Lunar mission are considered Exploration Spiral 2 missions.

Exploration Spiral 3 (Lunar Base and Mars Testbed) Encompasses the capabilities necessary to execute a long-duration human lunar exploration campaign. This campaign requires development of extensive surface systems (e.g., habitation and surface power system). Robotic Precursor Missions that are scheduled to launch after the last Spiral 2 extended- duration lunar mission, and prior to the initial Exploration Spiral 4 mission are considered Exploration Spiral 3 missions.

Exploration Spiral 4 (Crew Transportation System Mars Flyby) Encompasses the capabilities to conduct a Mars flyby mission using elements of the Human-Mars Crew Transportation System. Upon completion of successful Mars flyby(s), Exploration Spiral 5 will commence. Robotic Precursor Missions scheduled to launch after the first CTS Mars Flyby mission, and prior to the first Human-Martian surface mission are considered Spiral 4 missions.

Exploration Spiral 5 (Human Mars Surface Campaign) Spiral 5 encompasses the capabilities necessary to execute human Mars exploration missions. Robotic Precursor Missions scheduled to launch after the final Mars flyby mission, and prior to the start of Exploration Spiral 6 (content currently undefined) are considered Spiral 5 missions.

Ground Operations Phase Begins with the start of mission planning. Representative activities include: mission planning, training, receipt of government hardware/software, acceptance, test, checkout, repair, inspection, assembly, integration, servicing and countdown activities. Also includes ground contingency, emergency, abort and turnaround operations. Phase ends with vehicle liftoff.

Ground Support System This system provides all common ground-based capabilities (e.g., mission control, launch-site processing) needed to execute Exploration missions. Facilities and capabilities that are unique to a single Exploration System, such as the CTS, will be included as part of the system it supports.

Guidance and Control The process of directing the movements of a space vehicle, including selection of a flight path and making changes in attitude and speed.

Inclination The angle between the plane of an orbit and the Earth’s equator for all geocentric orbits.

In-Space Support System (IS^3) This system will encompass capabilities provided by infrastructure elements (e.g., a communication satellite or network) that are placed in orbital, or lunar/planetary locations. These capabilities are exclusive of those provided by elements of the DSS.

Independent Technical Authority (ITA) A responsibility owned by the NASA Chief Engineer, which is then delegated through the issuance of warrants. A warrant holder is designated as compliance officer over an identified set of engineering and technical requirements or standards.

Integrated Logistics Support (ILS) Is an approach that enables disciplined, unified and iterative management of support considerations into system and equipment design. ILS includes development of support requirements that are related to readiness objectives, to design, and to each other. Requirements in turn drive acquisition of required support; ILS is then employed during the operational phase.

Initial Lunar Phasing Orbit Used in Spiral 2 and 3 to define the orbit where the CEV will assume delta V requirements for a potential docking in lunar orbit. Defined by the following parameters: Altitude: 100 km x 500 km +/**- (TBD-6)** km **(TBR-34)**; Maximum inclination error with respect to the Lunar Reference Orbit; 0.5 degrees **(TBR-28)**.

Launch Availability The likelihood that a given launch will be achieved without a scrub once the mission timeline (first element launch for a multiple launch mission) or the launch countdown call to stations (for a mission scenario involving a single launch) has commenced. Launch availability is composed of four elements: system availability, launch probability, launch site weather constraints and abort weather constraints. Launch Availability can be expressed as: P(LA) = P(SA) x P(LP) x P(LW) x

P(AW)

Where:
P(LA) = Launch Availability (overall probability of achieving a launch)
P(SA) = System Availability (probability of hardware being acceptable for launch)
P(LP) = Launch Probability (probability that the vehicle limits are not violated by upper level winds or other natural environment phenomena)
P(LW) = Launch Weather (probability that other launch site weather constraints are not violated)
P(AW) = Abort Weather (probability that abort weather constraints are not violated)

Launch Azimuth The initial heading of a powered vehicle at launch.

Launch Opportunity The period of time during which the relative position of the launch site and orbital plane permit a launch vehicle to perform the ascent function.

Long-Duration (Lunar Mission) Human missions to the lunar surface that require pre-deployed Surface Systems. This capability is a requirement in Exploration Spiral 3, and encompasses surface stays from 42 days (threshold) up to 98 days (objective) **(TBR-70)**.

Low Earth Orbit (LEO) A stable orbit around the Earth with a minimum orbital altitude of 170 km.

Lunar Architecture Focused Trade Study Ongoing engineering analysis (led by NASA JSC) of lunar architecture and mission design options, in support of Exploration architecture decision-making. Results of this study are captured in document ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”.

Lunar Ascent Orbit Used in Exploration Spirals 2 and 3 to define the orbit that the LSAM must achieve when launching from the lunar surface. Defined by the following parameters: Altitude: 100 km +/- **(TBD-8)** km; Inclination angle (wedge angle) with respect to Lunar Reference Orbit: Maximum of 10 degrees **(TBR-71)**.

Lunar Reference Orbit Used in Exploration Spirals 2 and 3 to define the lunar orbit for rendezvous and docking of Exploration elements. Defined by the following parameters: Altitude: 100 km +/- **(TBD-8)** km; Inclination: Optimized for the mission.

Lunar Surface Access Module (LSAM) Provides crew transport to the lunar surface from the Lunar Reference Orbit and return from the surface to the Lunar Ascent Orbit.

Mating The act of mechanically connecting together two major elements of a system. Mating can be performed in space, through docking or berthing, or on the ground through docking, berthing, or other interfaces.

Mission Capable Refers to the status of an Exploration flight element or mated elements, which have sufficient consumables to fully execute its intended mission from its current location in space.

Mission Opportunity Refers to the Earth departure window to conduct a mission to another planetary destination such as the Moon or Mars. Typically constrained by orbital mechanics and the design of the Exploration System. If assembly of elements in Earth orbit is required, then "Mission Opportunity" refers to the departure window from Earth orbit based on the capability of the Exploration System.

Mission Phase Definitions Used as the basis for functional flow and decomposition of reference Spiral 3 human exploration mission. The Mission Phases identified were Ground Operations, Earth to Orbit, Earth Orbit Operations, Earth Orbit to Destination Vicinity, Destination Vicinity Operations (A), Destination Vicinity to Surface, Surface Operations, Destination Surface to Destination Vicinity, Destination Vicinity Operations (B), Destination Vicinity to Earth, Earth Reentry, and Recovery (see associated definitions).

Net Habitable Volume The functional pressurized volume left available to the crew after accounting for the loss of volume due to deployed equipment, stowage, trash, and any other items which decrease functional volume. The gravity environment corresponding to the habitable volume must be specified.

Objective Used in requirements language to define the desired capability above the threshold that should be evaluated for feasibility and affordability. Capabilities above the objective are not expected to be pursued or analyzed.

Payload The onboard scientific and exploration utilization (i.e. ISRU) equipment carried by a given spacecraft, generally quantified in terms of mass and volume. Also expressed as the entire mass delivered by a launch vehicle, to orbit.

Polar Regions of the Moon Defined as the area between 80-90 degrees **(TBR-74)** lunar latitude (threshold), with an objective of 70-90 degrees **(TBR-76)**.

Probabilistic Risk Assessment A set of methodologies employed to determine quantitative probability a given end state or states (e.g., Loss of Mission, Loss of Crew) will occur. Probabilistic Risk Assessment results can be used to develop or validate Fault Trees and Failure Modes analysis. They also can be used as a tool for making design and logistics decisions.

Proximity Operations Orbital flight operations conducted during any period when two or more vehicles are operating near enough to affect one another (e.g., prior to or post rendezvous and docking).

Recovery Phase Begins with completion of Earth surface landing and includes recovery forces operations, vehicle safing, vehicle configuration for recovery, crew egress, crew return to post-mission facilities. Ends with vehicle recovery to post-mission facilities for refurbishment or disposal.

Remotely Commanded Operations The capability to operate a vehicle, system, or subsystem from an external location (e.g., mission control). Remotely commanded operations do not require the presence of an onboard crew.

Robotic Precursor Mission A robotic spacecraft mission that supports The Vision by achieving scientific objectives and/or through preparing for future human exploration activities.

Robotic Precursor System Robotic spacecraft that are developed to execute missions that prepare for and support future human exploration, and to accomplish science objectives.

Safety-Critical Software Software is safety-critical if it meets at least one of the following criteria:
1. Resides in a safety-critical system (as determined by a hazard analysis AND at least one of the following:
    a. Causes or contributes to a hazard.
    b. Provides control or mitigation for hazards.
    c. Controls safety-critical functions.
    d. Processes safety-critical commands or data.
    e. Detects and reports, or takes corrective action, if system reaches hazardous state.
    f. Mitigates damage if a hazard occurs.
    g. Resides on the same system (processor) as safety-critical software.
2. Processes data or analyzes trends that lead directly to safety decisions (e.g., determining when to turn power off to a wind tunnel to prevent system destruction.)
3. Provides full or partial verification or validation of safety-critical systems, including hardware or software subsystems.

Segment Used in the CTS requirements development process to express the identity of two or more elements mated together and operating jointly in a given set of mission phases. Segments defined this way facilitate functional decomposition of capabilities throughout the reference Exploration Spiral 3 mission. For example, the In-Space Transportation Segment is comprised of the CEV and an Earth Departure Stage, and comprises the CTS from the Earth Orbit Operations Mission Phase until CEV-EDS separation during the Destination Vicinity Operations Mission Phase. Other segments were defined as the CEV Launch Segment (CEV and CLV operating through separation in Earth orbit), the Destination Transportation Segment (CEV and LSAM operating in the lunar vicinity), and the Earth Return Segment (CEV only, upon separation from LSAM Ascent Stage).

Spiral Development Process A phased system of system development process that allows increasing capabilities to be achieved in support of long range objectives. While work can be accomplished concurrently against the objectives associated with multiple spirals, the completion of all objectives for a given spiral is considered necessary to enable achievement of the succeeding spiral. See associated definitions for Exploration Spirals.

Strategy to Task to Technology Process (STTP) Use of engineering analysis to validate architectural and mission design approaches, and identify technology investment needs.

Surface Operations Phase Starts at the completion of landing on the destination surface, including propulsion system shutdown and safing. Representative mission activities include: science operations, system and operational testing, surface EVA, assembly and maintenance, vehicle checkout, and preparation for ascent. Phase ends at initiation of ascent from the destination surface (i.e., T0).

System of Systems A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any portion of the System of Systems will degrade the performance or capabilities of the whole. The systems contained in the Exploration System of Systems (ESS) are: the Crew Transportation System, Cargo Delivery System, In-Space Support System, Destination Surface System, Robotic Precursor System, and Ground Support System. Requirements, constraints, and guidelines that apply to all human and robotic exploration systems are levied against the Exploration System of Systems, and may apply against any or all Exploration Spirals, as specified. The term “System of Systems” is sometimes expressed synonymously as “Super-system”.

Threshold Used in requirements language to define the minimum capability necessary to satisfy the requirement.

Transfer Volume The passageway between two connected element that can contain crew.

Wedge Angle The angle change that must be accomplished (i.e., delta-V capability) to exit an Earth Reference Orbit and achieve a desired Lunar Reference Orbit (see Lunar Reference Orbit).

4.2 Acronyms and Abbreviations

CDS	Cargo Delivery System
CE&R	Concept Exploration and Refinement
CEV	Crew Exploration Vehicle
CEVLS	Crew Exploration Vehicle Launch Segment
CLV	Crew Launch Vehicle
CG	Center of Gravity
CTS	Crew Transportation System
DSS	Destination Surface System
EDS	Earth Departure Stage
EI	Entry Interface
ECLSS	Environmental Control/Life Support System
ESMD	Exploration Systems Mission Directorate
ESS	Exploration System of Systems
EVA	Extra-Vehicular Activity
GN&C	Guidance, Navigation, and Control
GSS	Ground Support System
IRD	Interface Requirements Document
ILS	Integrated Logistics Support
IS^3	In-Space Support System
ITA	Independent Technical Authority
JIMO	Jupiter Icy Moon Orbiter
LEO	Low Earth Orbit
LRL	Lunar Robotic Lander
LRO	Lunar Robotic Orbiter
LSAM	Lunar Surface Access Module
NEDD	Natural Environments Definition for Design
NODIS	NASA Online Directives Information System
NP	NASA Publication
NPD	NASA Policy Documents
NPR	NASA Procedural Requirement (Document)
OAG	Operations Advisory Group

OSMA	Office of Safety and Mission Assurance
OSP	Orbital Space Plane
PRA	Probabilistic Risk Assessment
RFP	Request for Proposals
RPS	Robotic Precursor System
SRR	System Requirements Review
STD	Standard (Document)
STTP	Strategy to Task to Technology Process (or Panel)
TBD	To Be Determined
TBR	To Be Resolved
TPS	Thermal Protection System

4.3 Requirements Taxonomy

The following table is provided as a key to understanding the taxonomy used for requirement Unique ID numbers (i.e., the Unique ID number is shown at the beginning of each requirement statement).

System/Segment	Req. Number	Spiral
ESS (Exploration System of Systems Technical) **EPR** (Exploration Programmatic Requirements) **EPG** (Exploration Programmatic Guidelines)	**0001 - 9999**	**A = Spiral 1** **B = Spiral 2** **C = Spiral 3** **D = Spiral 4** **E = Spiral 5** **F = Spirals 1&2** **G = Spirals 2&3** **H = Spirals 1,2,3**
CTS (Crew Transportation System) **CVS** (CEV Launch Segment) **CEV** (Crew Exploration Vehicle) **CVL** (CEV Launch Vehicle)		